Relative Permeability and Capillary Pressure Controls on CO_2 Migration and Brine Displacement

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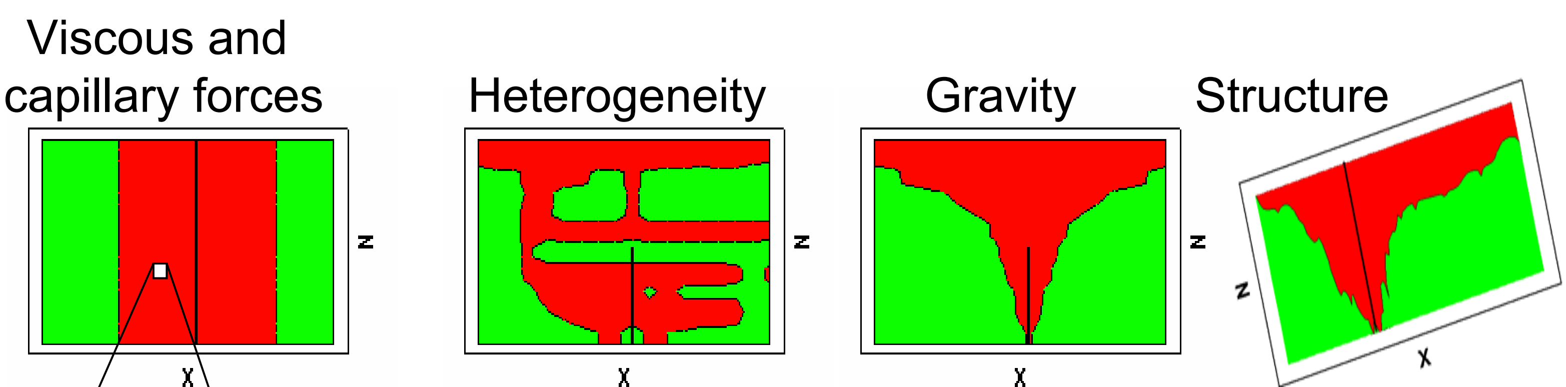
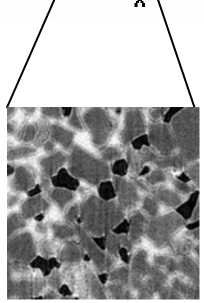
  - Liviu Tomutsa
  - Christine Doughty

Some Key Issues for CO_2 Storage in Deep Saline Aquifers

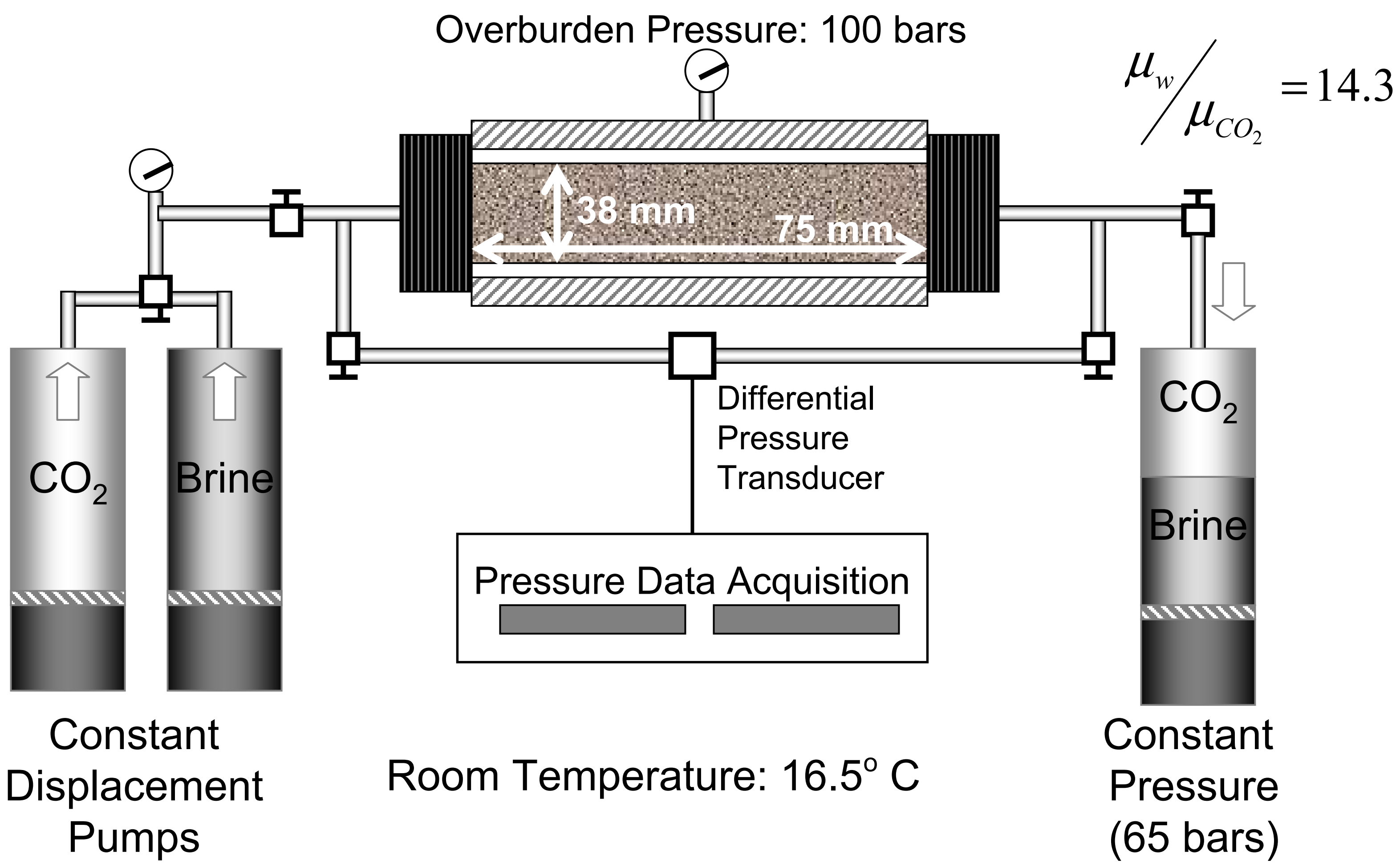
- What fraction of the pore space can be filled with CO_2?
- How big will the CO_2 plume be?
- How much CO_2 will be dissolved?
- How much will capillary trapping immobilize CO_2?
- Can accurate models be developed to predict CO_2 fate and transport?





Answering these questions depends on the complex interplay of viscous, capillary, buoyancy forces and heterogeneity and structure on CO_2 plume migration.

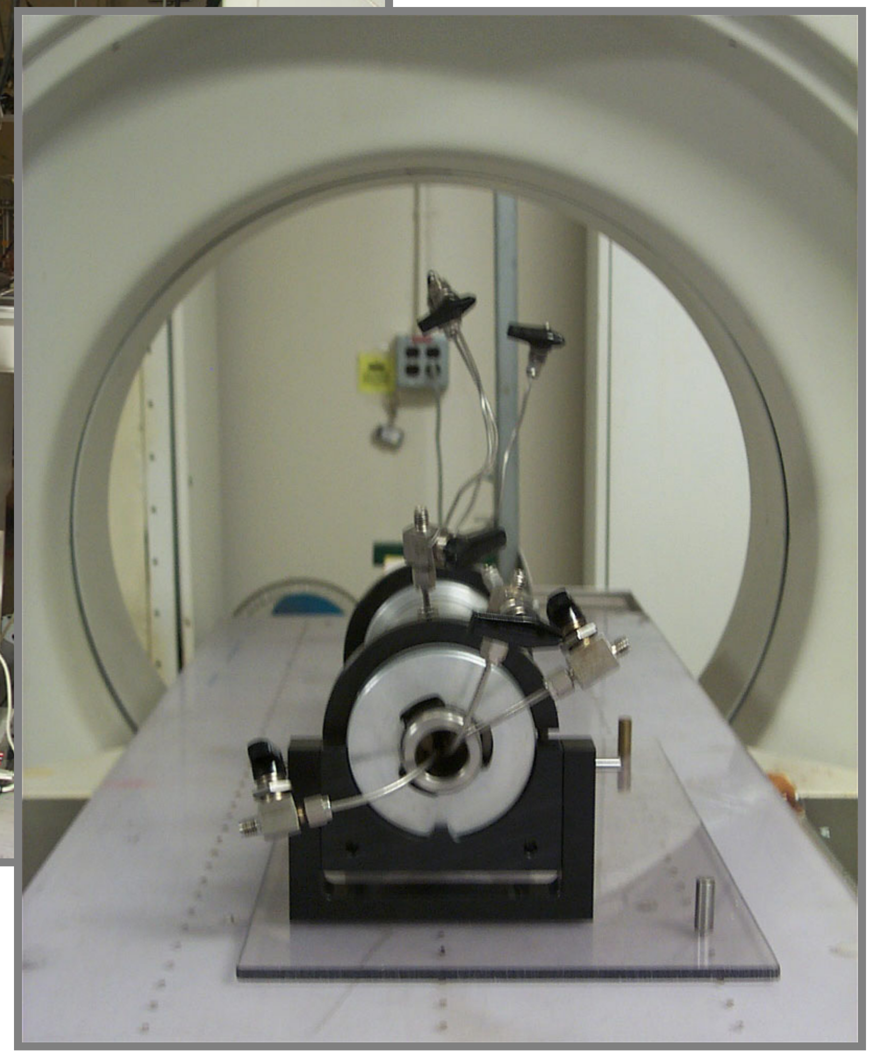
Core-flood Set-Up for Relative Permeability Measurements



*Brine composition: CO_2 saturated brine with 0.5 molar potassium iodide

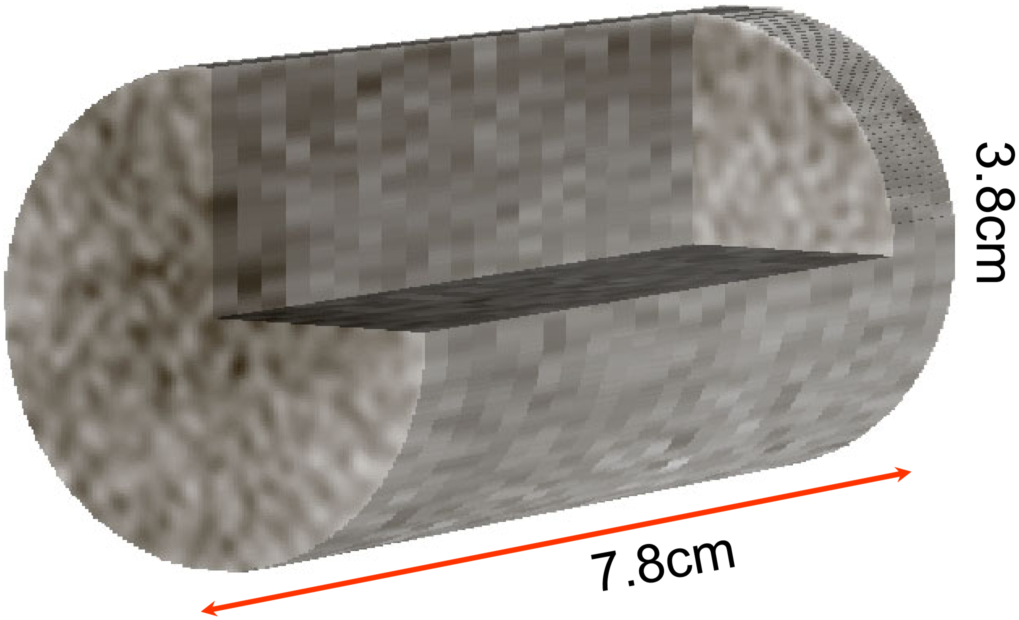
Core-Scale Imaging of CO_2 Distributions

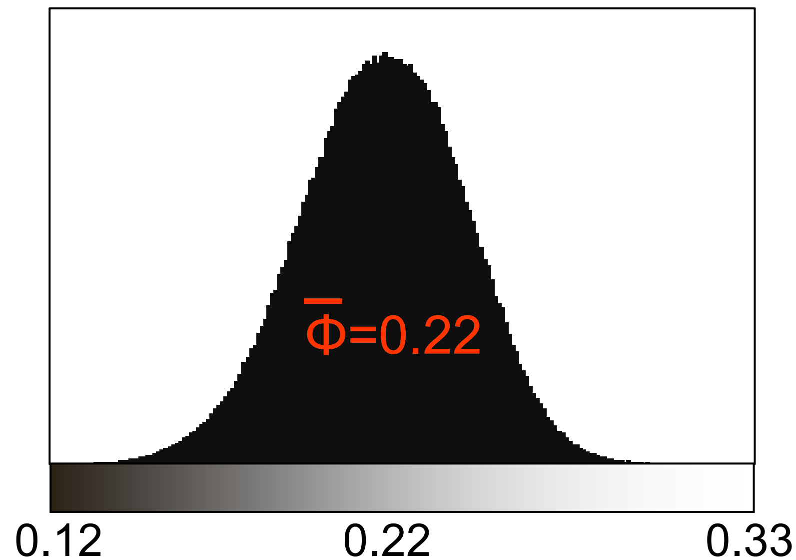
High Pressure Pumps

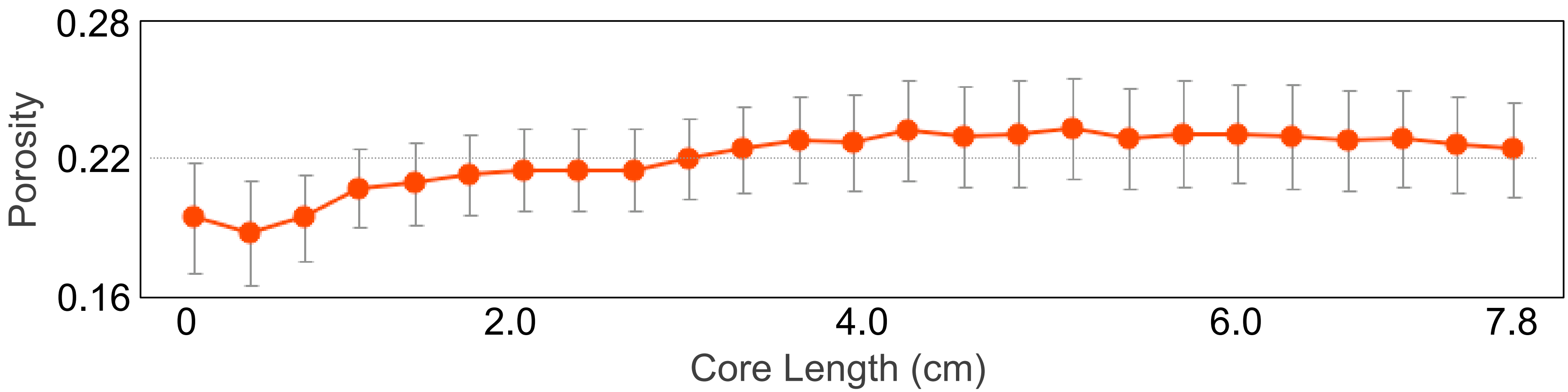


Core Holder
In Scanner

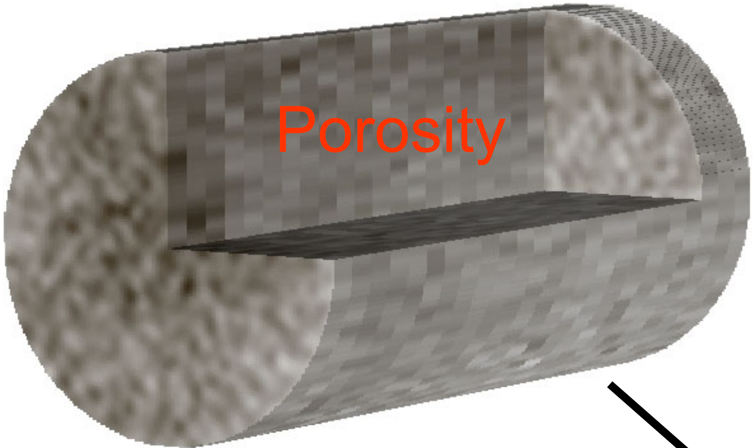
CT Scans Measure Core Porosity





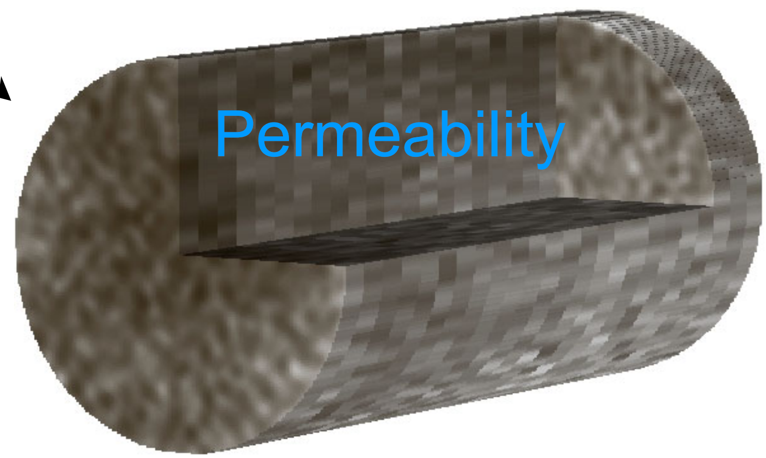


Calculation of Permeability

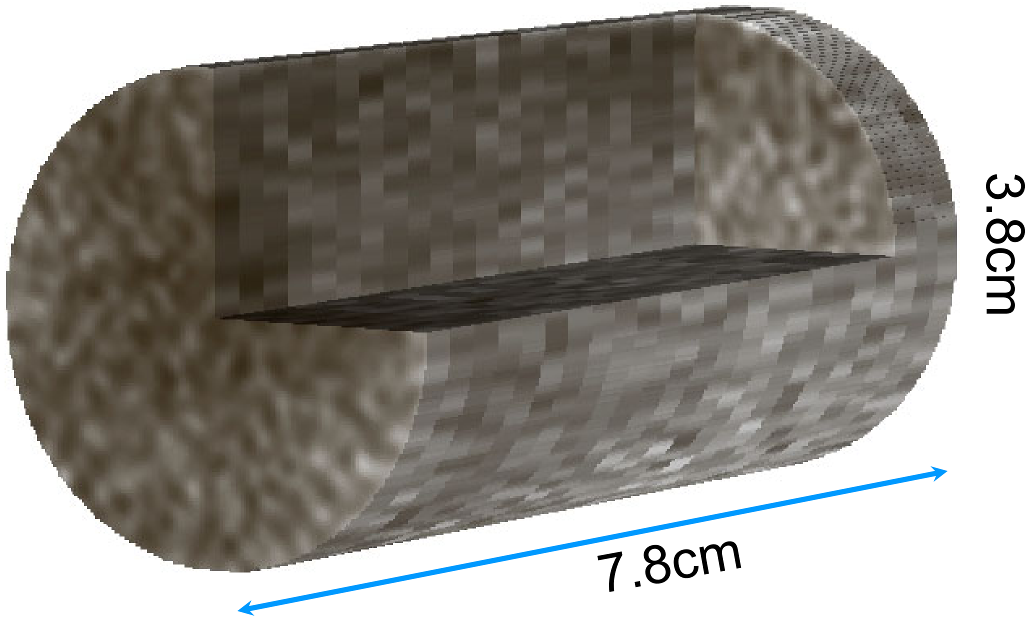


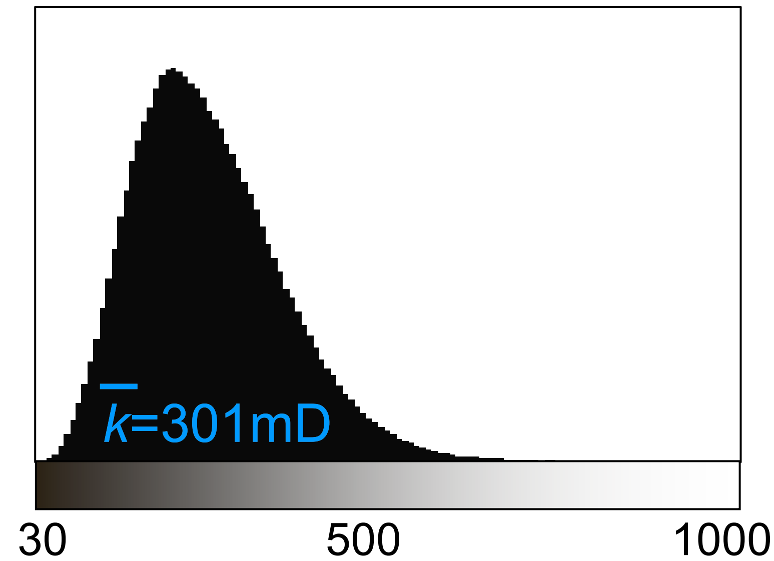
Kozeny-Carmen

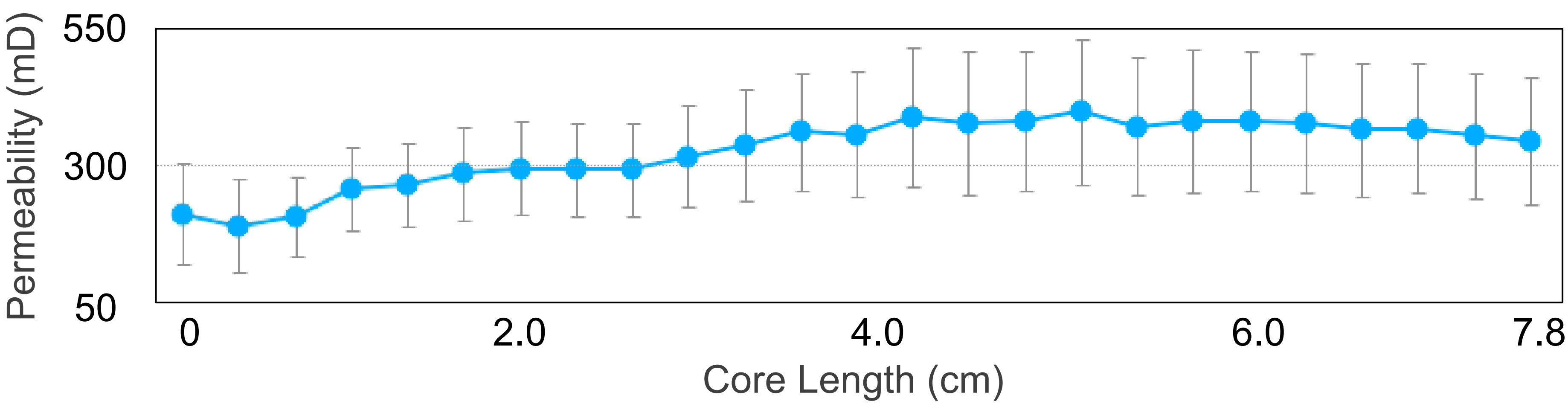
$$k_i = \frac{\Phi_i^3}{S(1-\Phi_i)^2}$$



Core Permeability Distribution

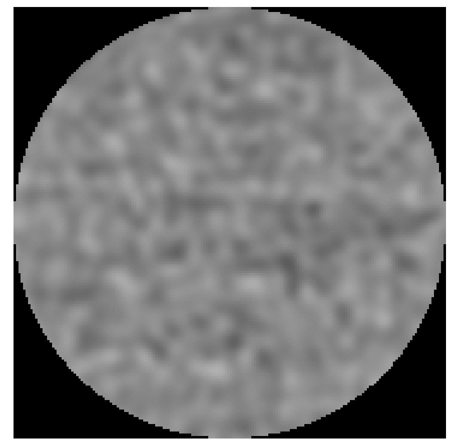






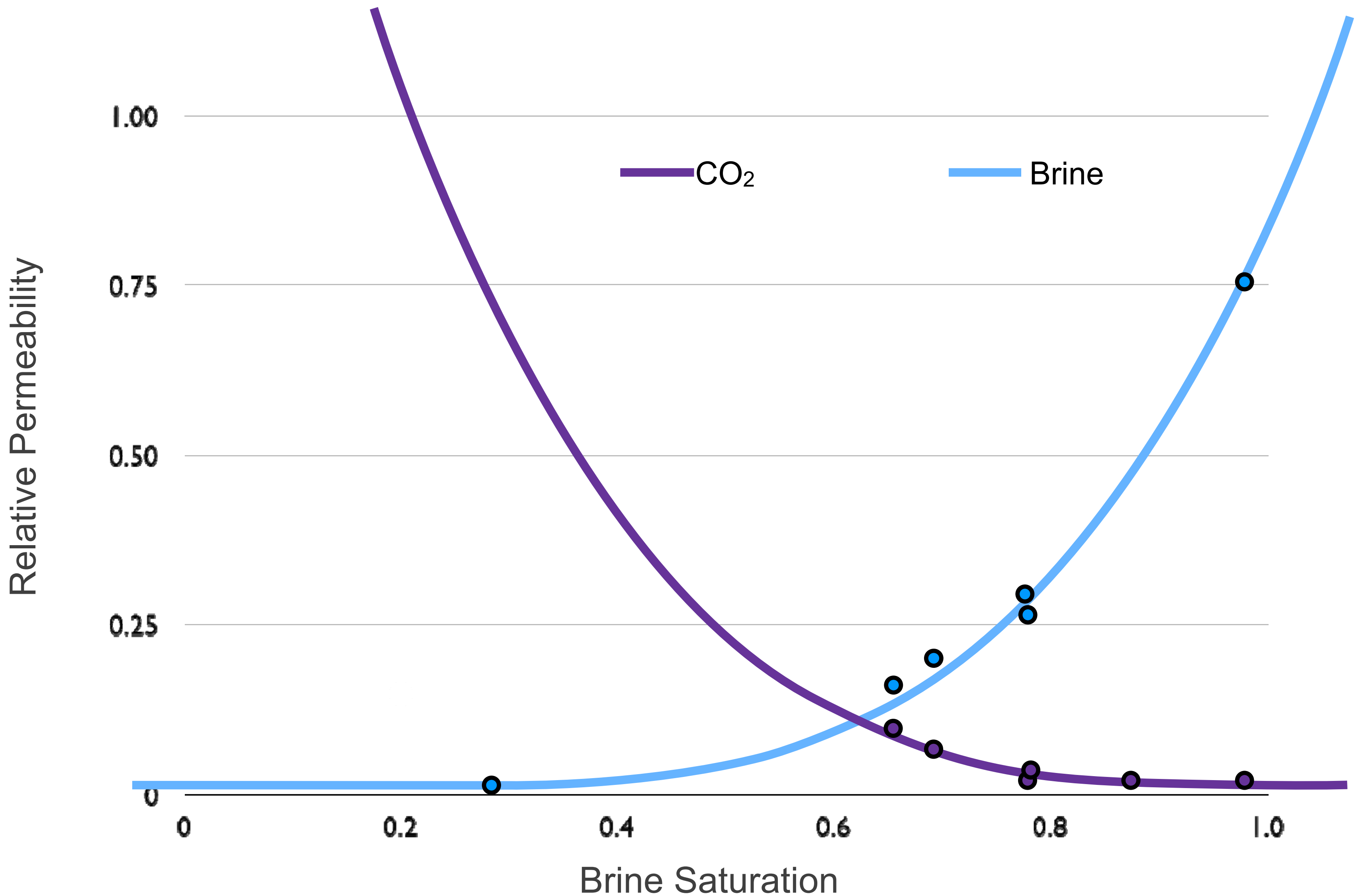
Laboratory Injections of Various CO_2-Brine Proportions

- Experimental Setup:
  - 5%, 10%, 20%, 50%, 80%, 90%, 100% CO_2 injections
  - 3mL/min constant flow-rate
  - 6.89MPa constant back-pressure
  - 16 ±2°C lab temperature
  - Brine contains dissolved CO_2
  - CO_2 contains dissolved water

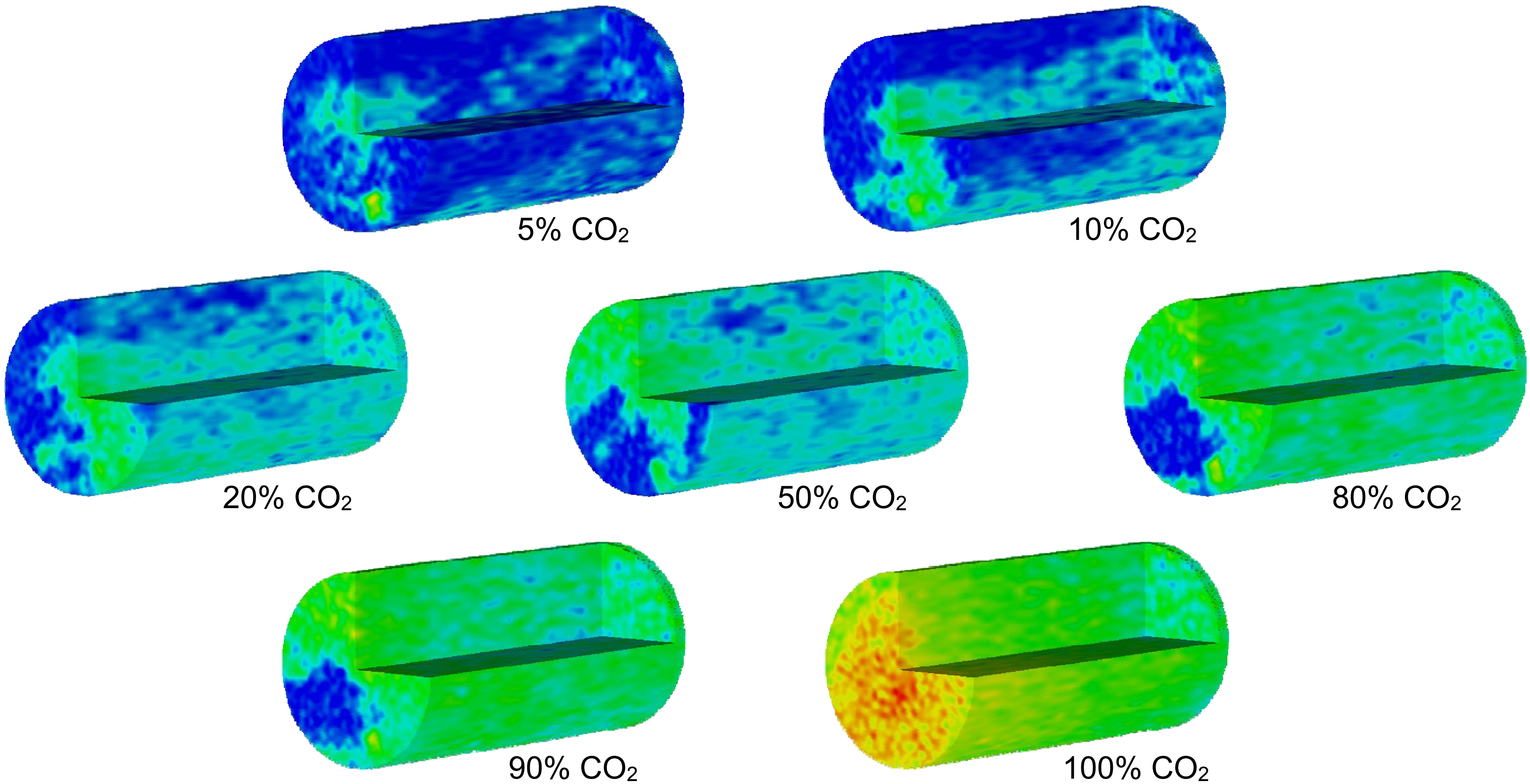


- Measure CO_2 Saturation with CT Scanner
  - Digitally reconstruct image

Relative Permeability Curves



Small-scale CO_2 Saturation Variations



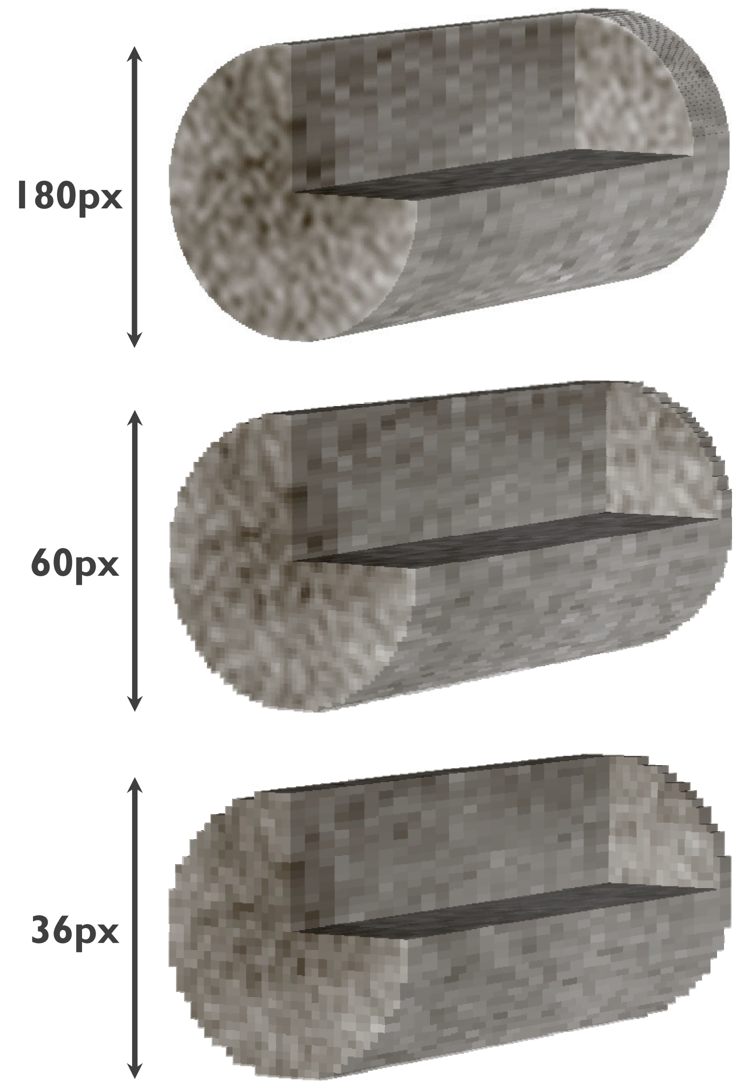
Sub-corescale saturation variations generally overlooked in relative permeability measurements.

Simulated Injection of Various CO_2-Brine Proportions

- Simulation Cases
  - 10%, 90%, 100% CO_2 injections
  - 3mL/min constant flow-rate
  - 6.89MPa constant back-pressure
  - 16°C constant temperature
  - Brine contains dissolved CO_2
  - CO_2 contains dissolved water

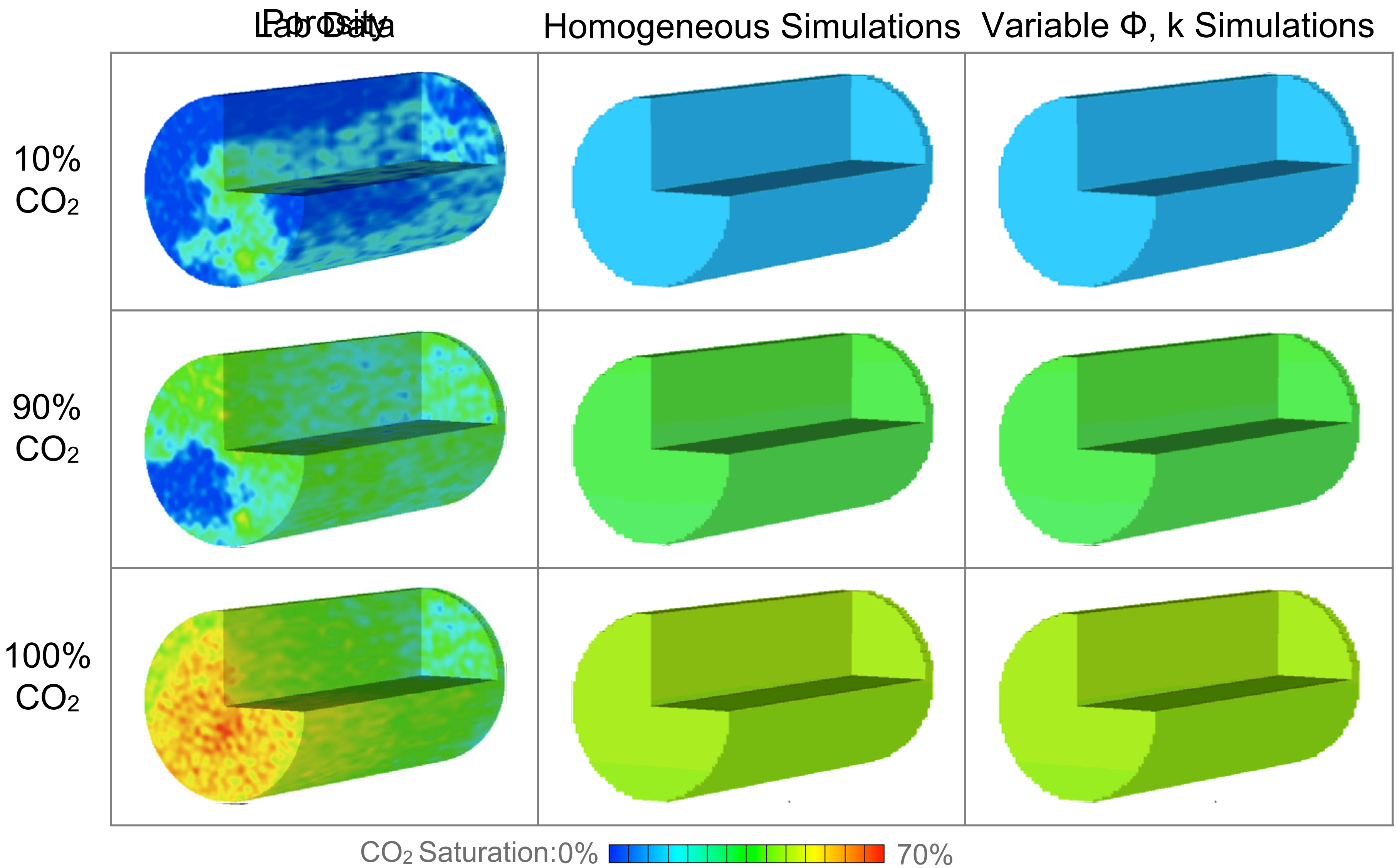
- Core Characterization
  - Porosity/permeability "map" coarsened
  - Relative permeability/capillary pressure curves matched to experimental curves

- TOUGH2 (Pruess, LBNL)

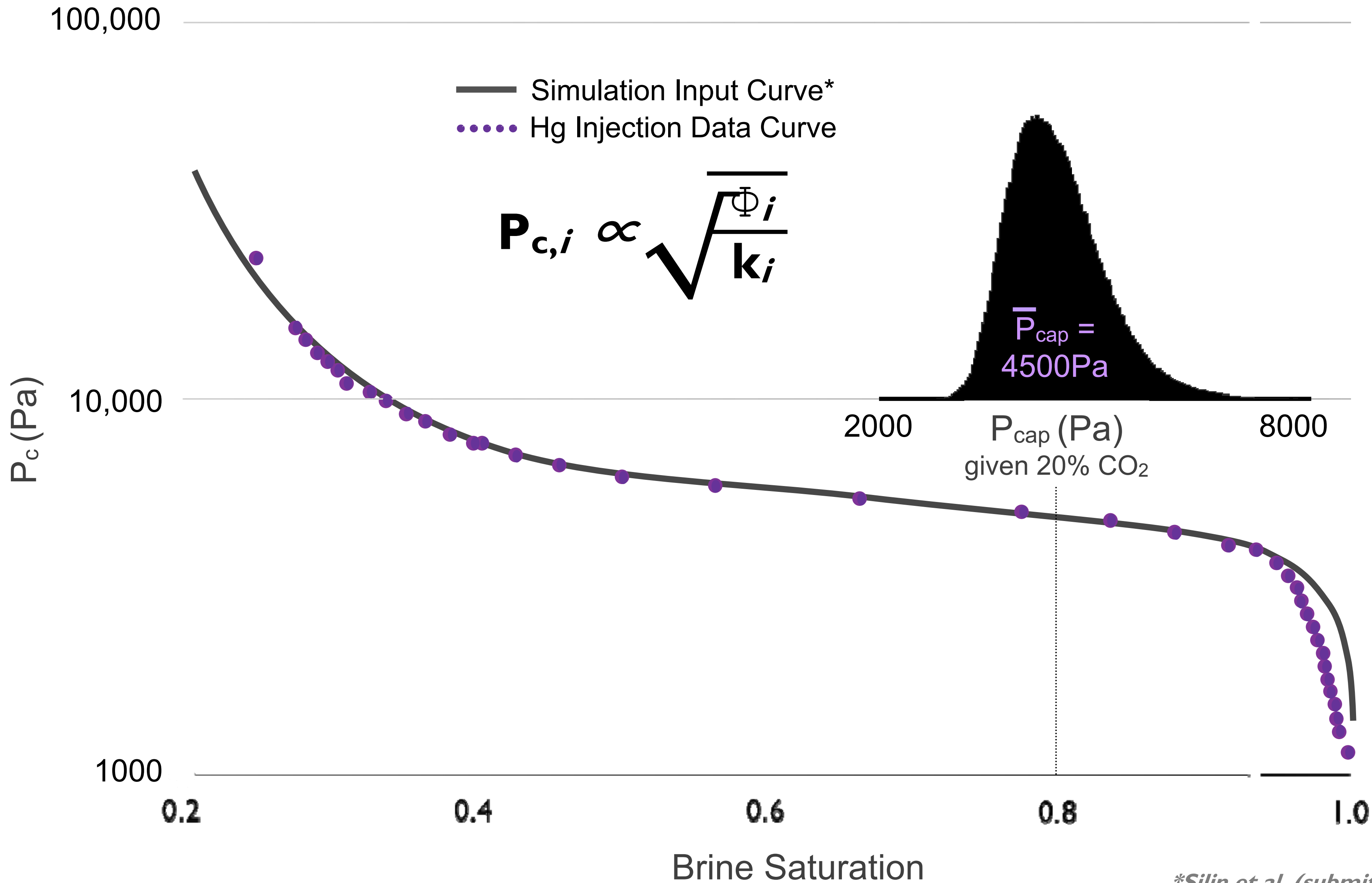


Simulated CO_2 Saturations

Constant P_c Produces Homogeneous CO_2 Saturations



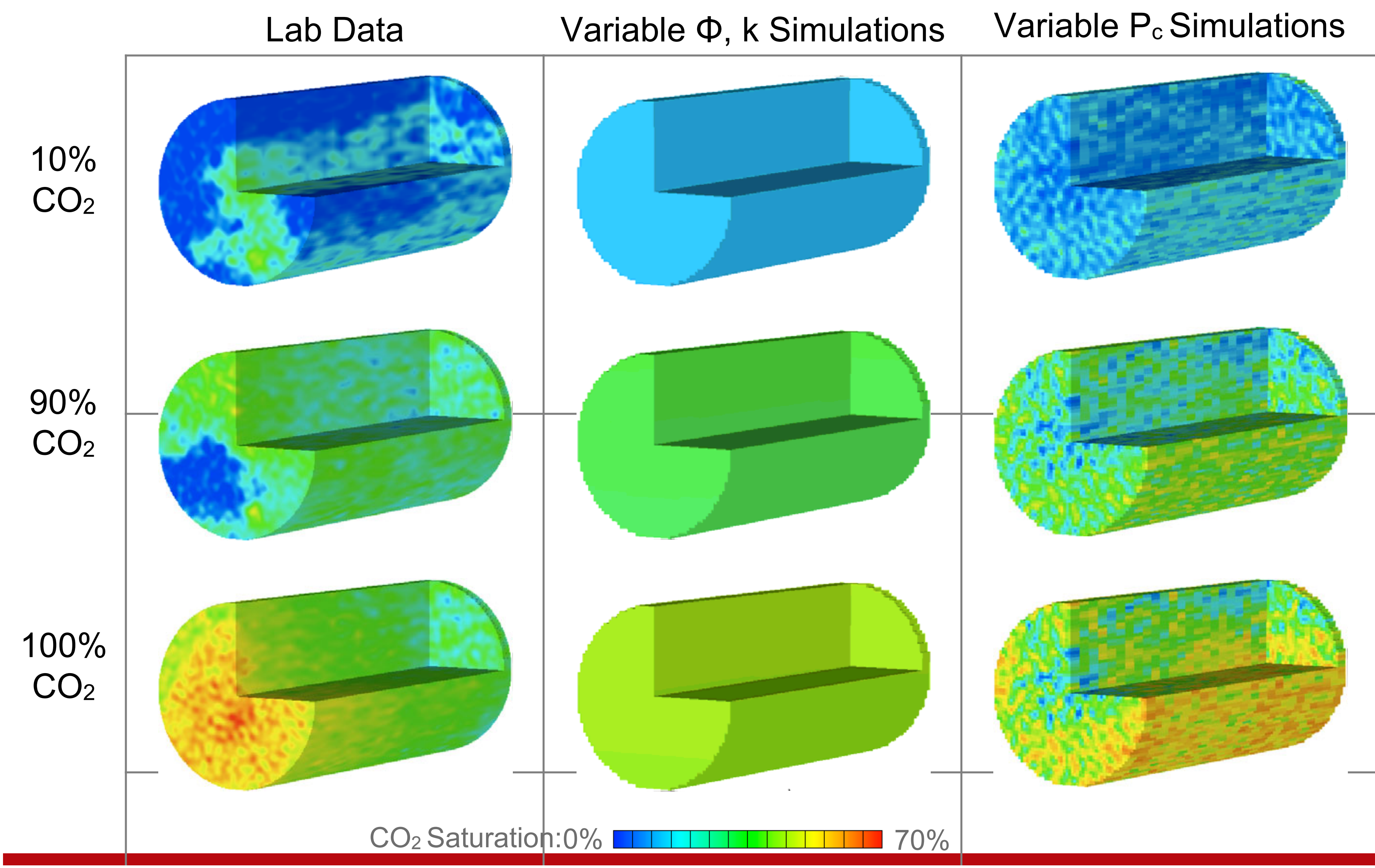
Fitting Capillary Pressure Curve



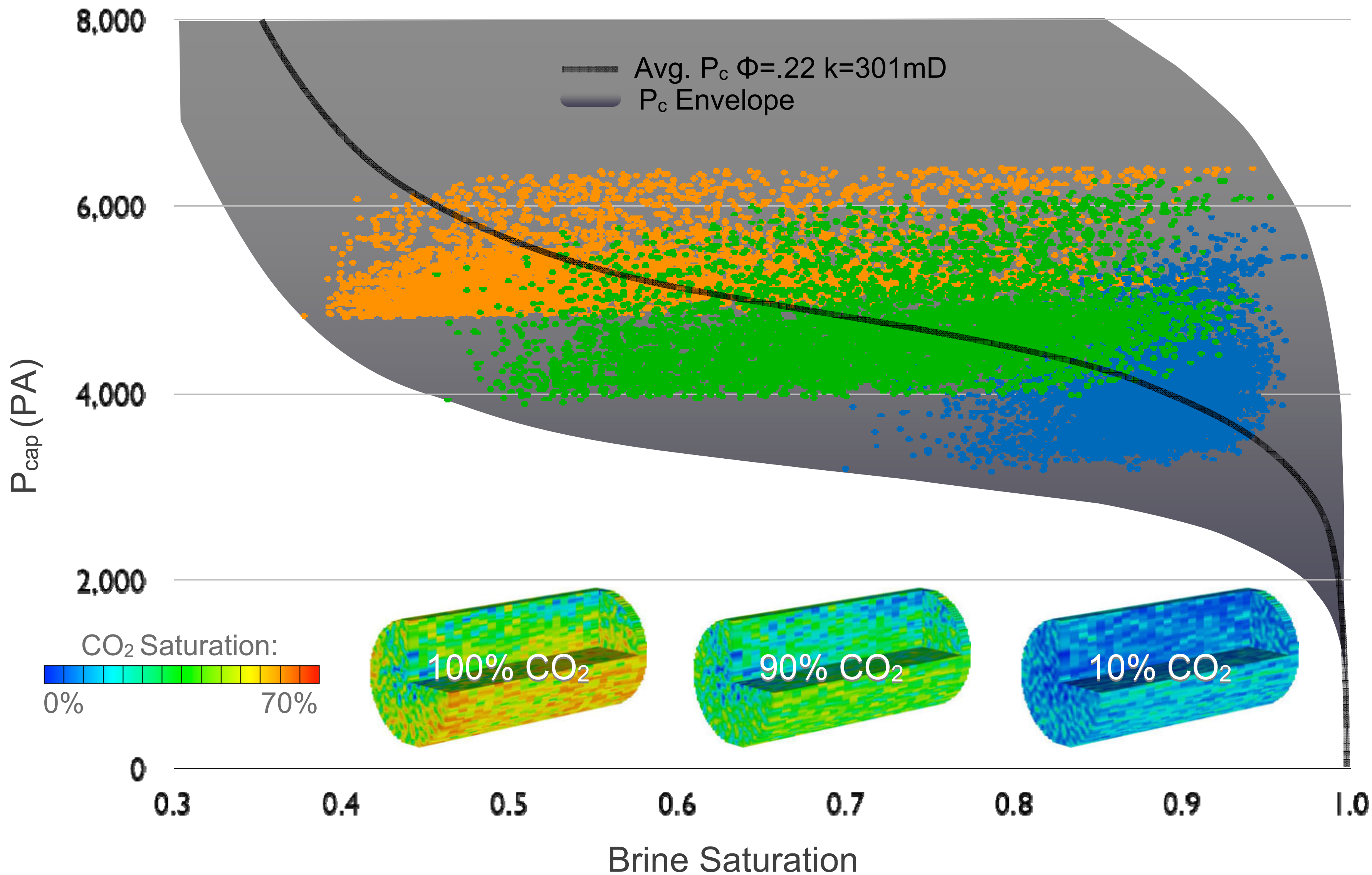
*Silin et al. (submitted, 2007

Simulated CO_2 Saturations

Variable P_c Produces Small-scale CO_2 Saturation Variations



Capillary Pressure Curve



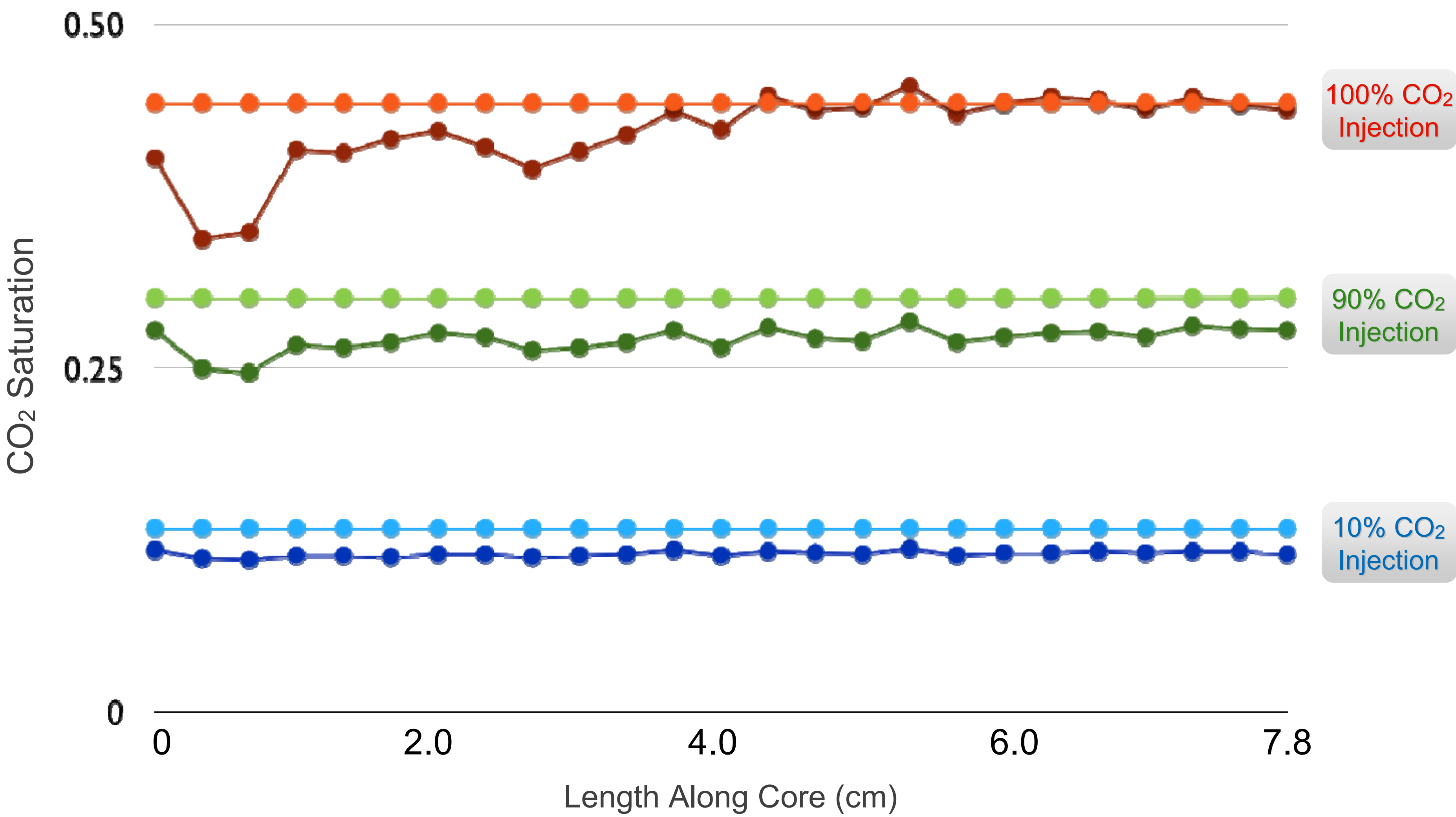
Why should we care?

Why Should We Care?

Average CO_2 saturation is:

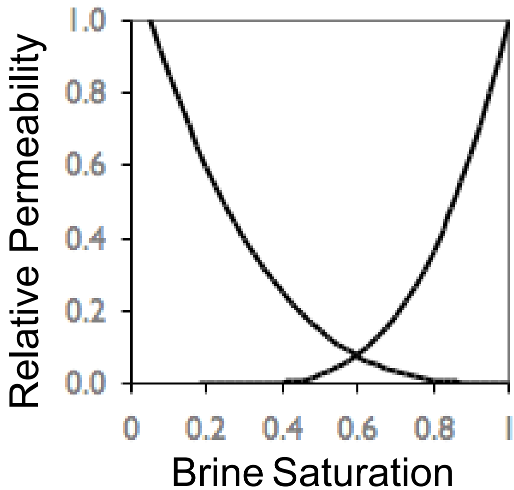
- Decreased by sub-corescale heterogeneity
- Flow-rate dependent
- Affected by simulation grid resolution

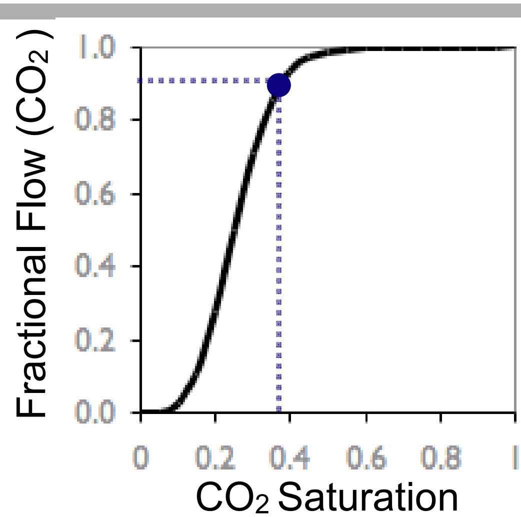
Subcore-scale Heterogeneity Decreases CO_2 Saturation

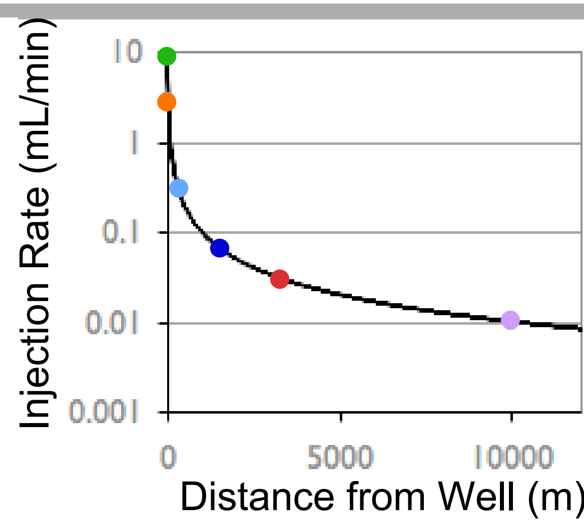


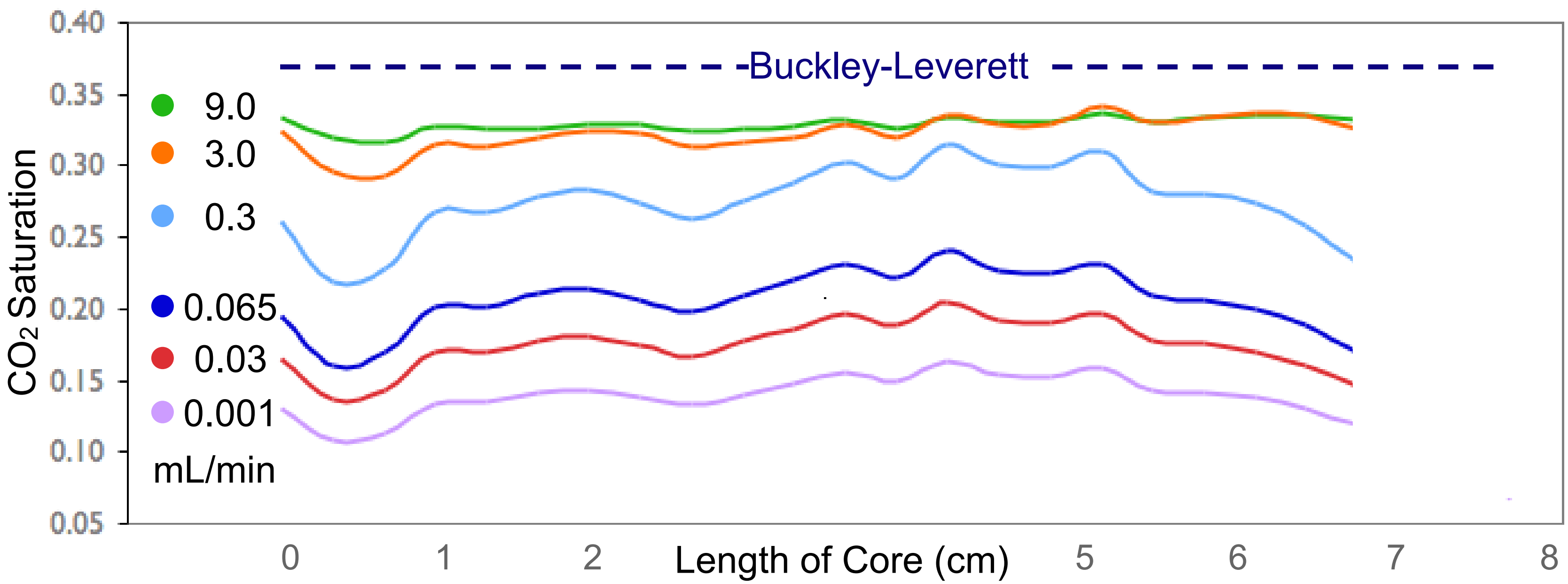
Effects of Flow Rate on CO_2 Saturation

90% CO_2 Injection Simulation

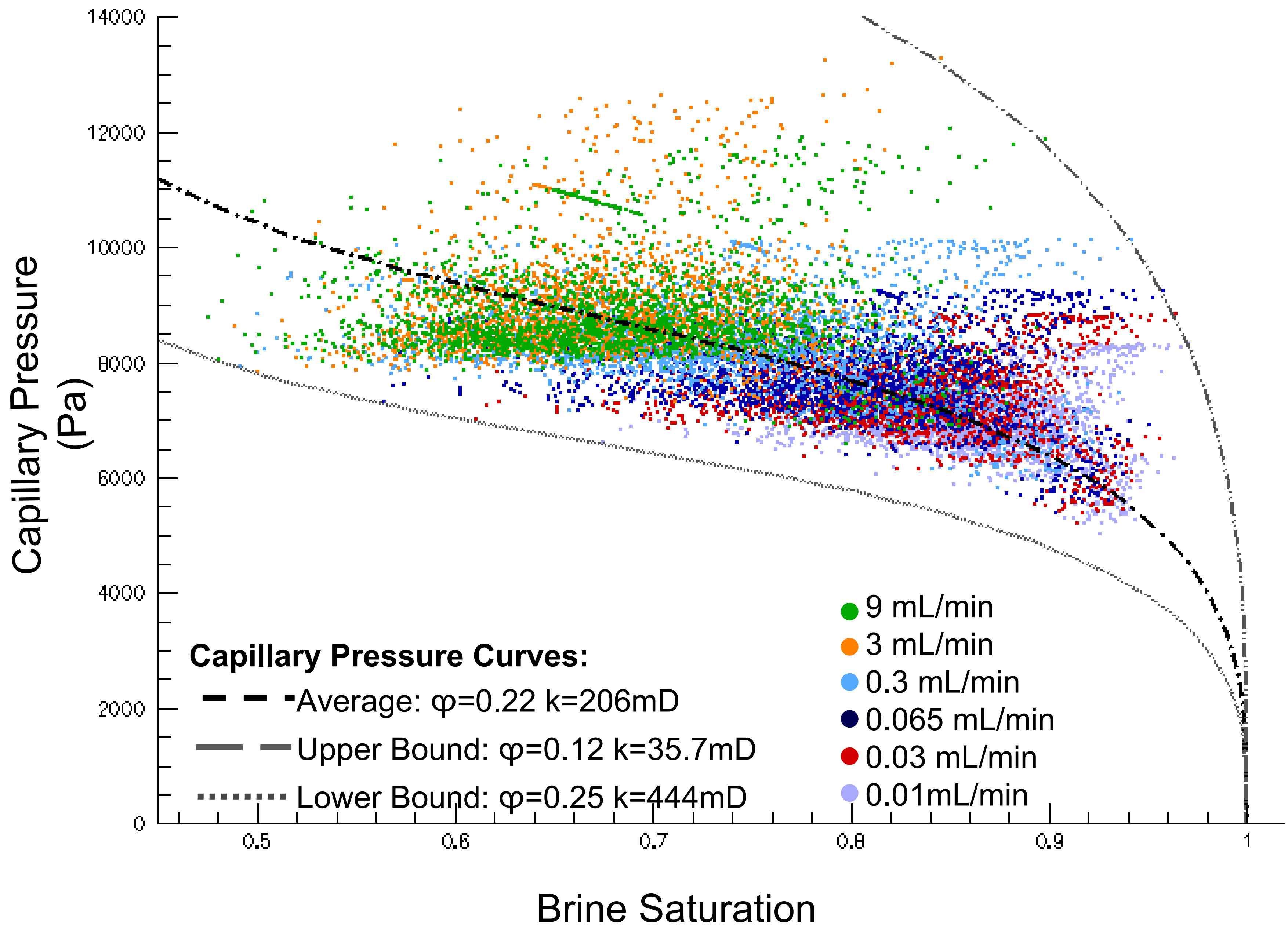




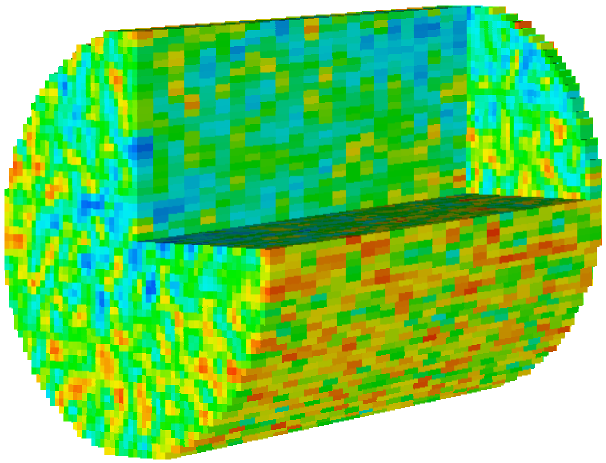




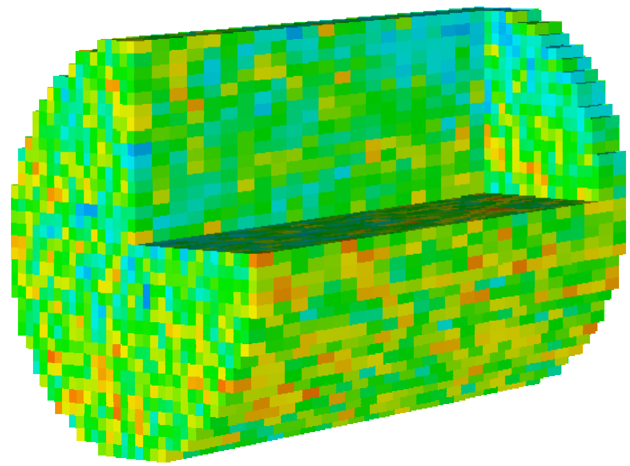
Capillary Pressure Distribution at Different Flow Rates



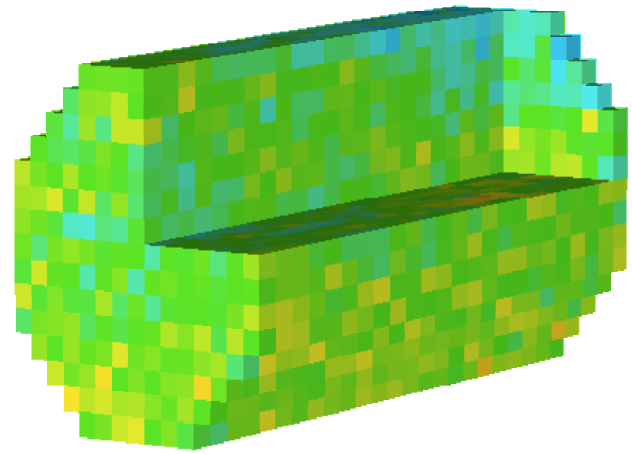
90% CO_2, 10% Brine Injection
Variable Simulation Resolutions



Grid Size: 0.6x0.6x3mm
Grid Count: 67,350

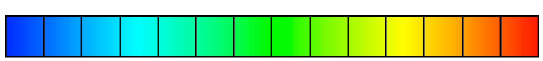


Grid Size: 1x1x3mm
Grid Count: 23,400

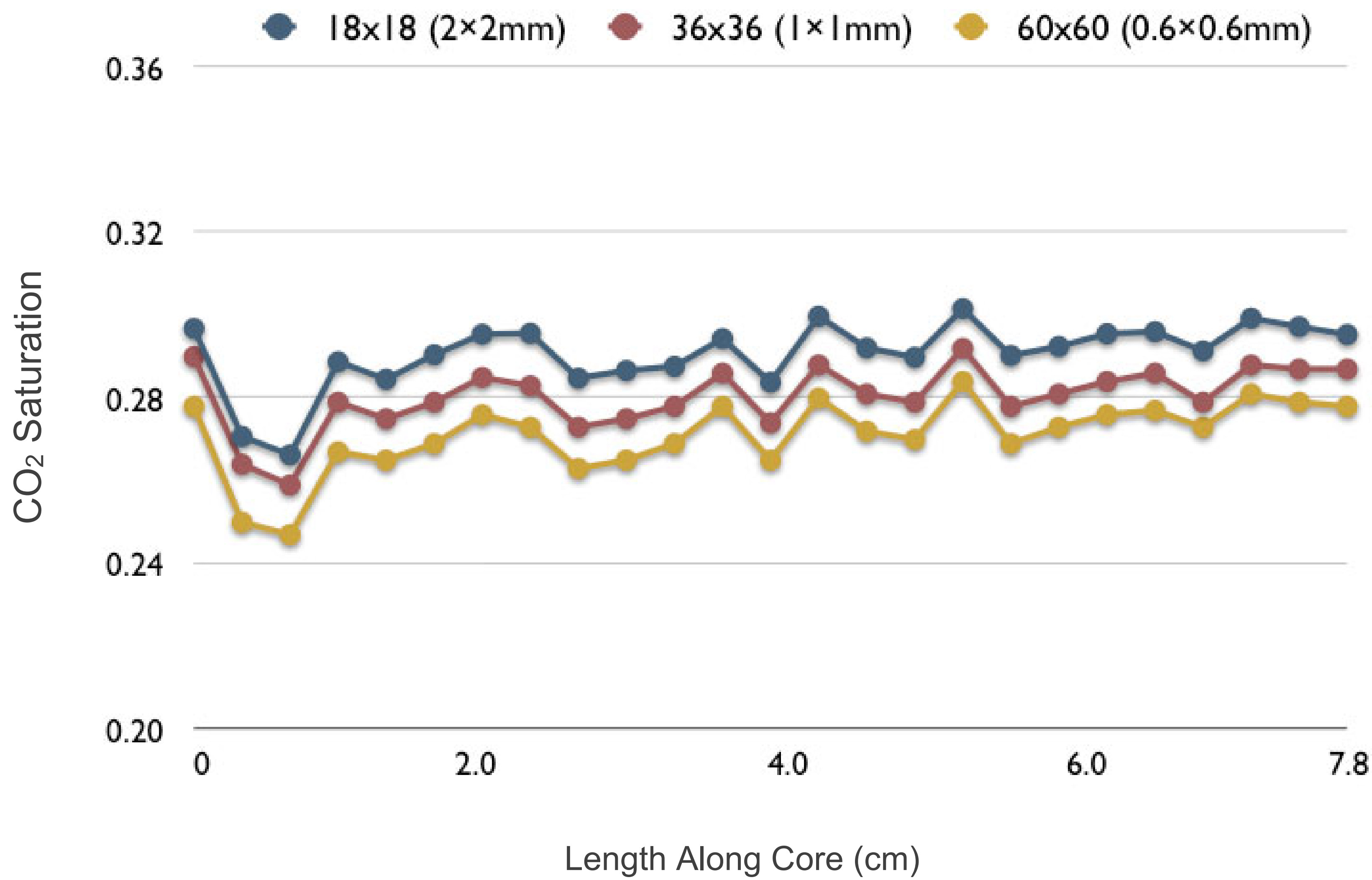


Grid Size: 2x2x3mm
Grid Count: 5,400

CO_2 Saturation:



Finer Simulation Grids Decrease CO_2 Saturation



Conclusions

- Core-scale multi-phase flow experiments reveal strong influence of sub core-scale heterogeneity
- Spatial variations in capillary pressure behavior control CO_2 saturations
- CO_2 saturation:
  - Decreases due to bypass of low porosity regions
  - Decreases at lower flow rates
  - Predictions depend on grid size
- Similar phenomena are expected at all spatial scales
- Fundamental research needed to improve model predictions
  - Fundamental process understanding based on lab and field experiments
  - Up-scaling strategies that accurately include the effects of sub-grid scale heterogeneity
  - Calibration and validation of predictive models